Living like a Mars rover

All About Space caught up with TED Talk speaker Nagin Cox, the Curiosity rover's spacecraft engineer, who lives and works on Martian time

Interviewed by James Horton

Before joining the Jet Propulsion Laboratory (JPL) you served with the US Air Force for six years. Did you always see yourself progressing onto interplanetary space missions?
Actually, I did. I have been interested in working for JPL since I was 14, so I've always had a bit of a one-track mind. I was very fortunate to have served in the military; they funded all of my education from undergraduate to postgraduate degrees, so I couldn't have gotten to where I am today without having served. But then there came a point where, for as much fun as I was having in the military, I wanted to switch back to my original goal. I was working in military space operations at the time and I wanted to resume my quest to join JPL. I felt that it would take longer than it did, but I was fortunate enough to join NASA within a year of leaving the Air Force.

You've had the privilege to work on three of the rovers to have landed on Mars. What stands out to you as the most exciting?
The landings are very hard to beat for sheer excitement and nervousness. But separate from the initial landings and driving the rover from the landing platform and onto the surface – as we did during the Mars Exploration Rover (MER) missions – there have been so many. One that I specifically remember is when the project scientist came into the flight operations room and told us that the water on Mars had once been drinkable. That was quite a moment, and we were told that they wanted to share the information with the flight team before it was announced.

There are many moments like that, where we hear results as they're being developed, and then we can start to think about where we're going to drive to next to investigate the idea further. Overall, as the engineers, our role is to drive the rover and make sure that it's okay, but we also get to participate daily with the scientists as the story develops.

And then of course there are the exciting milestone sols. At first, we thought Spirit and Opportunity were designed for 90 sols – or optimistically maybe we could get an Earth year of use out of them – but 14 years later we continue to be amazed. And although I don't work on Opportunity any longer it's hard to forget your first rover. [Note: since this was first published a dust storm cut communications with the Opportunity rover. NASA believes it has experienced a low-power fault and they are currently trying to contact it.]

> "There is always a question about the toll it takes on the people on Earth, and the complications that surround it"

Had the idea to amend your working hours to Mars time (by coming into work 40 minutes later every day) been introduced when you joined the rover missions? Why was that decision made?
I was on MER from day one, and whether or not to operate on Mars time for each rover, or a lander like Phoenix, is an ongoing discussion. The basic idea is that you can be more efficient with the rover if you work as if you're actually on Mars [by elongating the Earth day by 40 minutes to accommodate Mars' slower rotation], rather than operating strictly according to the Earth day. However, there is always a question about the toll it takes on the people on Earth, and the complications that surround it. So we're constantly thinking about whether it's necessary to do that; we ask whether we've learned enough about operating on the Red Planet to either shorten or lengthen the amount of time spent working on Mars time to make it more sustainable. We only have a few data points about this, so it's a constant conversation about whether we need to operate on Mars time, and for how long. It's a fascinating conversation that goes on and on; I've recently joined the Mars 2020 rover team, and Mars time is still an ongoing discussion.

Cox at Mission Control back in August 2012

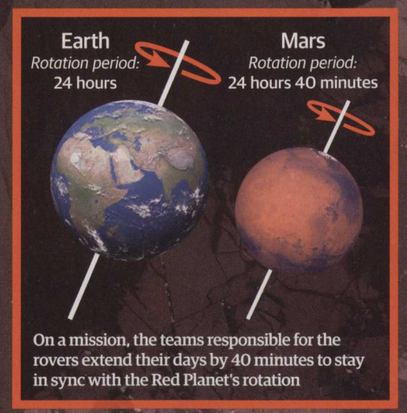
INTERVIEW BIO

Nagin Cox
Nagin Cox is a spacecraft engineer at NASA's Jet Propulsion Laboratory (JPL) and part of the team responsible for operating the Curiosity Mars rover. She has a master's degree in Space Operations Systems Engineering and joined JPL in 1993 after six years with US Air Force. She has worked on NASA/JPL's Galileo mission to Jupiter, the Kepler telescope that's hunting for Earth-like exoplanets and three of the Mars rovers.

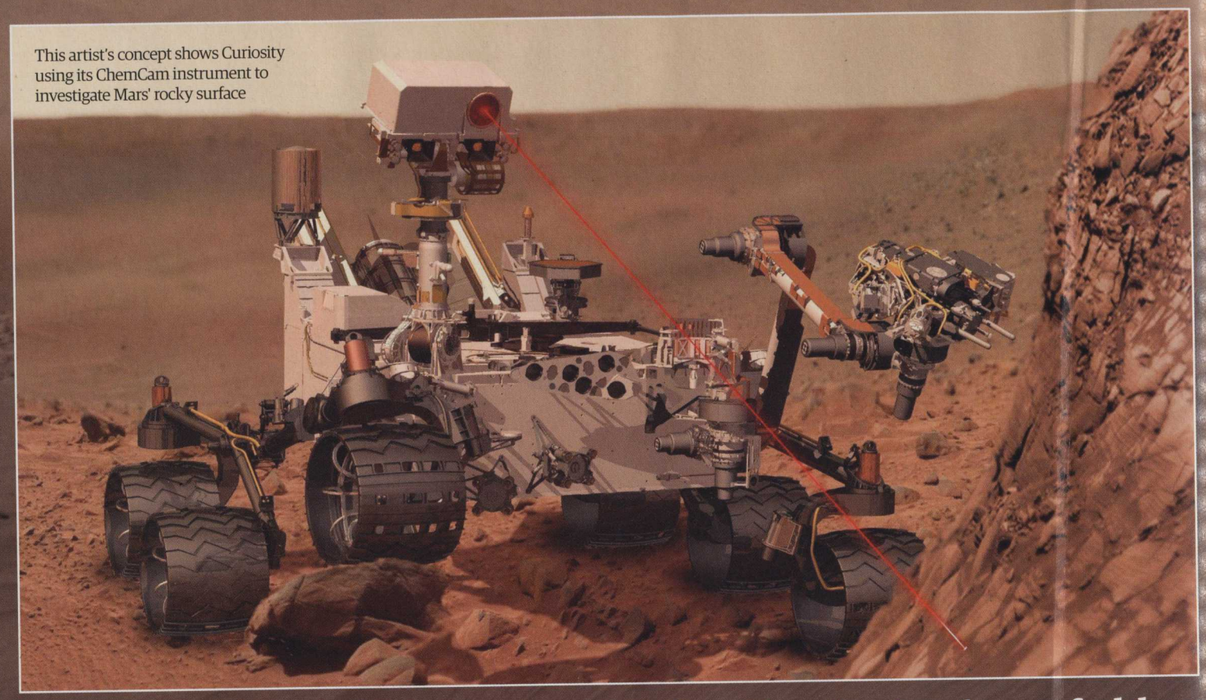
What were the main obstacles your team faced when trying to operate by Martian days instead of Earth days?
Those of us who live in Pasadena [California] and work on the missions have the advantage of remaining at home, but when you're switching your own body clock to Mars time it's important to consider the impact it has on your family. For the scientists and engineers coming from other parts of the country and the rest of the world, they have a different set of challenges. They'll be living in either townhouses or rented apartments with roommates who are also likely on Mars time, so there's not such a sense of inconveniencing those around you. However, those scientists and engineers are gone for three months or more from their families.

But whether living at home with families or away from them, all of us had to face the challenge that the Sun rises above the Earth at a certain time, and you can't block out everything. The errands and daily activities that you have to do are still there so you have to learn where the 24 hour fueling stations, diners and grocery stores are; but there's still a lot you can't do. It's a challenge to conduct the rest of your Earth life while your work life is on Mars time.

Were these changes why you and the other members of your team came to think of yourselves as 'Martians'? Did you feel more like that than 'Earthlings'?
The thing with calling ourselves Martians and feeling disassociated with others was because we were out of sync. A good parallel is to think about going camping, say when you're away from

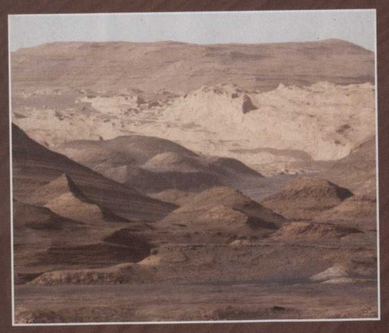


On a mission, the teams responsible for the rovers extend their days by 40 minutes to stay in sync with the Red Planet's rotation



This artist's concept shows Curiosity using its ChemCam instrument to investigate Mars' rocky surface

Nagin outlines the Mars Science Laboratory mission in a presentation at Dryden, Ontario, describing it as the most difficult planetary mission ever attempted



The Mars Science Laboratory operations team members have to meticulously plan Curiosity's route through the ridges of Mount Sharp

"It felt like exploration in the days of old. We would drive the rover over a hill and wonder what we were going to see"

civilisation for a week. You immediately become very attuned to nature but grow disconnected with the news and other things. In the same way, when we were coming into work 40 minutes later every day our attention was on work, on Mars. So although we weren't removed from information about the Earth we were there to do a job, and that job was on Mars. And once our working hours had rotated into the Earth night we grew very disconnected. For those three months, we had to put our Earth lives on hold until the end of Mars time, and so the dissociation eventually just happened.

To help your team adapt to Mars time you were given watches that run slightly slower to match the Red Planet's rotation. Is there anywhere we can get our hands on a Martian-time watch?
At the time they were specially made. The first were made for Mars Pathfinder, which was in 1997, and then when I got mine in 2003 for Spirit and Opportunity, they were being made by two local jewellers. At the time they were quite inexpensive; I had two – one for Spirit and one for Opportunity – and they were only $70 (£55) apiece. But now they're such a speciality item that a mechanical Mars watch is over $400 (£310), however, there are apps for Android and digital watches that can perform the same function.

How instrumental do you feel the findings of the Mars Exploration Rovers have been in our efforts to understand the Red Planet?
I think they have been very instrumental in our understanding of Mars as a whole, but they do fit into a larger overall program. Because the rovers are on the surface and we can drive them around, we can bring a different data set than the orbiters. But the orbiters are also key. When we started out, we didn't have the HiRISE camera on MRO [Mars Reconnaissance Orbiter] with its incredible resolution, and at that point it felt like exploration in the days of old. We would drive the rover over a hill and wonder what we were going to see because the pictures from orbit weren't at the level of today's incredible cameras. Now we can get a better sense from orbit of where we're going and what's the right path to take, which makes us very efficient. And secondly the orbiters also make discoveries on their own based on their global data set.

If you imagine trying to understand Liverpool by just having a car that's able to drive around, but without a larger picture of the city and Great Britain to go with it, it would be difficult. So the rovers, the orbiters and even the landers – which don't move around, but give us a picture of what's going on under the planet's surface – all go together. For example, every so often you'll hear people say: "how many times is NASA going to announce water on Mars?" and you can see how, to the general public, it seems like they've heard it all before. However, as part of the scientific method, it is reassuring that we continue to find evidence that there was once liquid water on the surface of Mars in the past and that we are able to evolve that story.

"They may be growing lettuce on the ISS, but we don't have a lot of experience in hydroponics anywhere else"

How is the Curiosity rover mission progressing?
Well, we've been making our way through Bagnold Dunes as part of our ascent of Mount Sharp, and for me as someone who has been working on the rover from before we even landed, it's exceptionally gratifying to see the parts of the mission that take a long time to happen. When we picked the landing site of Gale Crater and saw that there was this remarkable dune field surrounding the base of Mount Sharp, we had to ask ourselves how we were going to get through those dunes. We had to pick a decent crossing location and be aware that it was going to take a considerable portion of the mission to traverse down to a point where we could navigate between the dunes safely to continue our ascent. So it's been gratifying to have us arrive at a point that we've been heading towards for a while now and seeing it as a milestone in our exploration story, which has been a long time coming.

What new information will Mars 2020 bring?
Each rover builds on the previous so this time we'll be caching samples taken from the surface of Mars, but we'll be leaving them there for the next mission to bring back. We'll also be taking equipment that can help us take the next step in detecting life, which will provide us with the ability to detect different kinds of biosignatures.

We have to be patient, given that we're trying to get samples that are going to come back to the Earth. These are the samples that generations of scientists will be using, the same way that we still use the Moon rocks. Our scientists will want every last bit of information they can get from Mars before selecting a sample, and you can understand that. This is going to be their legacy to future scientists and students all around the world. For me it is very interesting to work on a mission where we in operations have an equal standing in designing the rover for this historic step in gathering samples, which the next rover mission will then come back and get – and that will be the hard mission!

You've spoken before about the rovers acting as pathfinders for human astronauts to follow. Do you feel that this goal is achievable in the coming decades, given what we now know about Mars?
I do think that it's achievable. It has been achievable to send people to Mars for some time now, but it's a matter of how many resources the world wants to devote to it. One can invest the time and the resources to send people to Mars, but often the goal is not yet one of colonisation but more likely something similar to the permanent presence we've had in Antarctica for 100 years, where we have very small scientific research bases.

Now you could brute force your way to Mars using rockets, sending all the needed supplies, assembling in orbit and those sorts of things. But there's a lot of engineering work that needs to be done in parallel to getting humans ready to send to Mars. For example, on 2020 we have an instrument on the rover called MOXIE (Mars Oxygen In-Situ Resource Utilization Experiment), which is going to be a prototype that can take in Martian atmosphere and pull apart the carbon dioxide to make carbon monoxide and oxygen, and that will be the very first step on that path.

I actually worked on that instrument for a while, and the idea is that you could scale up from the Mars 2020 prototype and then eventually you'd be able to send a mission to Mars that can land an oxygen production plant on the surface. That could then sit there and make oxygen for a couple of years until the astronauts arrive.

So to make Mars sustainable – even in the way that we call our bases in Antarctica sustainable – there is a lot of engineering work that has to be done first. They may be growing lettuce on the International Space Station, but we don't have a lot of experience in hydroponics anywhere else. Also there's the idea of going back to the Moon or an asteroid or cis-lunar space as a proving ground before going to Mars. Getting there will also be down to international cooperation, because to go alone just doesn't seem to make any sense.

Finally, your namesake asteroid, 14061 Nagincox, is shooting through the cosmos. How does it feel to have a celestial object named in your honour?
Even when it's brought up I'm still so amazed by it, and it transpired in such a surprising way. I was in Italy with the State Department just outside of Florence and I was giving a presentation, and in one of those crazy coincidences the discoverers (Ulisse Munari and Maura Tombelli from the Cima Ekar observatory) happened to be at this lunchtime talk in a library, and afterward they rushed the podium and said: "we're going to name an asteroid after you!" It was such a tremendous honour that I'm still beyond amazed. And I'm also really glad it's not an Earth-impacting asteroid!

Described by Cox as one of the most exciting parts of the mission, the Curiosity rover's landing is facilitated by a sky-crane manoeuvre

understanding of Mars when it landed on 6 August 2012. With a multitude of sample analysis instruments, cameras and even a hi-tech laser it is absolutely unmatched in its design.

The mission iwas designed to last 686 Earth days, approximately one Martian year. During this time Curiosity carried out some groundbreaking science on the surface in addition to testing out new technologies and methodologies. The rover is somewhat autonomous, possessing the ability to move between two points while avoiding obstacles. However, to do so requires extensive daily input from the ground. "The challenge of [MSL] is that you can't just program it and collect your data in two weeks to see how it's going. You actually have to tell it what to do every day. That's what's going to pose a real challenge.

"One of the things that really makes this mission pretty exciting is that the amount of information that we have about the landing site from our orbital assets is phenomenal," says Meyer. "We've already plotted out likely pathways of where to go, and it's great to approach it with that sort of prior knowledge because when we find something that's different it's a real 'aha!' moment."

Curiosity will be the fourth rover to land on Mars, succeeding Sojourner, Spirit and Opportunity, and NASA has made sure to learn from the previous missions to optimise the data returned from this one. "Certainly we have greatly improved operations, and we have a much better sense of the kind of realistic timing for what we can do and what we can ask the rover to do." Indeed, as previously mentioned, one of Curiosity's greatest advancements on its predecessors is a greater degree of autonomous navigation. "On any of the runs where the rover goes more than 30 metres [100 feet], it can be done autonomously because we'll have enough data to plot out a good path," explains Meyer. "If we don't have enough information [about the topography] the rover can decide if it has an obstacle in the way and avoid it. The big science driver for this mission is not within the landing area, it's actually going up Mount Sharp, so because of that there'll be a fair amount of driving to get to the minerals we're most interested in early on in the mission." The rover, however, won't be speeding along the Martian landscape. It will take its time, going very slowly indeed. "To go 100 metres [330 feet] is doable in a day," says Meyer. "In theory you could maybe go 150 to 200 metres [490 to 650 feet]. Part of that is the wheels don't roll that fast, and the other part is that after a certain distance it has to stop and reassess its environment."

The Mars Science Laboratory will be landing in an area known as the Gale Crater, a 3.8-billion-year-old crater 154 kilometres (96 miles) in diameter. At its centre is the aforementioned Mount Sharp, towering 5,500 metres (18,000 feet) high. It was one of four candidates for a landing site and ultimately received the nod, but why was it picked? "All four [proposed] landing sites were pretty compelling," explains Meyer. "All four sites give you evidence of a place that has had water in the past, so they all met our criteria of a place that we think could have been habitable at one point. Any one of them would have been fantastic, but Gale has evidence of water in its past and it has two major minerals that we think are indicative of different periods of time on Mars: clays and sulphates. There's also

Curiosity dwarfs the other Mars rovers by quite a margin

layering there, which we think will give a somewhat ordered history of Mars. Gale has sedimentary deposits that we think traverse a period of time when Mars went from being relatively warm and wet to what it is now: cold and dry."

The most interesting thing about Gale, though, is that it has the possibility of organics or, in other words, past or present signs of alien life. This ties in directly with one of the key goals of Curiosity's mission, namely discerning whether Mars was or is habitable, a question that no other mission has yet been able to definitively answer. "With any sedimentary deposit you have the potential for preservation of organic material," says Meyer. "One of the surprises of the Viking probe was actually that they didn't find organics. You would expect to find some because you get them from meteorites and the like. So the big science revelation [from Viking] was that something's happening on Mars that destroyed the organics, at least on the surface. So we're hoping that by going to a place where you have these deposits laid out, that something buried may be preserved."

To find these hidden clues to the Martian past, Curiosity has a variety of hi-tech instruments on board. These include ChemCam, a laser that will vaporise areas of rock for Curiosity to analyse, and SAM (Sample Analysis at Mars), an instrument suite that will discern the molecular and elemental chemistry of soil samples collected by a drill on Curiosity's extendable arm. Meyer is fairly confident that Curiosity would be the mission that would find signs of habitability. "We expect to find organics from meteorite impacts, brought in from outer space. We also expect to find organics that were made on the planet, so this is a great lead into that. And then of course the million dollar question is: are there organics made by Martian life?"

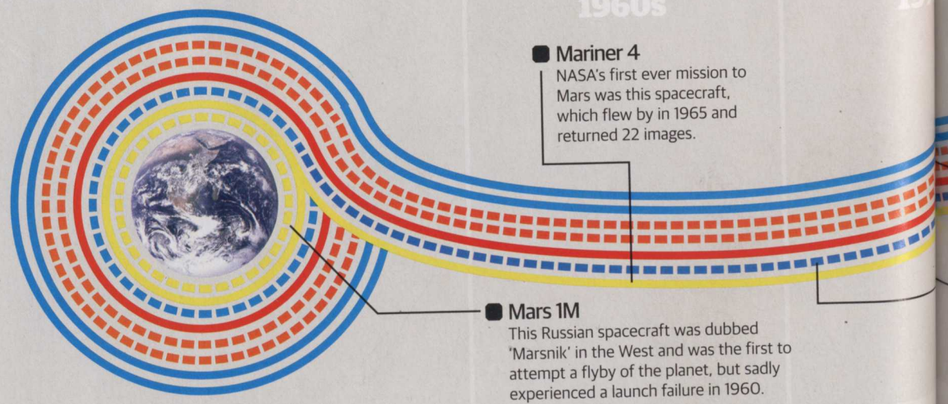
So, will MSL be able to answer that question? "Definitively, no," says Meyer, "but there is a possibility, there is always a possibility. Carl Sagan [the American astronomer] said that even a camera is a life-detection instrument. If something hops in front of the camera then you know it's alive. But the camera was not designed to specifically look for things to hop in front of it. MSL is designed to understand the environment in which it lands."

One of the most fascinating features of this Mars mission, and one that scientists hope might be used in future Mars missions, is the

Mars mission history

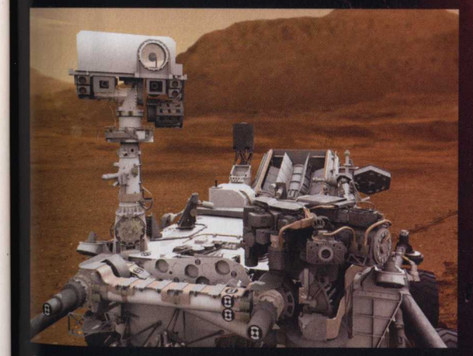
Dozens of robotic spacecraft have made the hazardous journey to the Red Planet since the Sixties, with mixed results...

Flyby: Success
Flyby: Failed
Orbiter: Success
Orbiter: Failed
Lander: Success
Lander: Failed


1960s
Mariner 4
NASA's first ever mission to Mars was this spacecraft, which flew by in 1965 and returned 22 images.
Mars 1M
This Russian spacecraft was dubbed 'Marsnik' in the West and was the first to attempt a flyby of the planet, but sadly experienced a launch failure in 1960.

4 goals of going to Mars

The Mars Science Laboratory has four primary scientific goals that it will be looking to fulfil in its time on the surface of Mars. While it will perform other research as well, it is these goals that pose the greatest unanswered questions about the Red Planet



Curiosity will be able to return high-resolution images and video from the surface of Mars thanks to its on-board cameras

Is, or was, Mars habitable?

One of the strangest things about Mars, surprisingly, is that life has not yet been found. The planet has been pummelled by meteorite impacts, thanks largely to its thin atmosphere, and therefore we would expect to find organics of some kind. Curiosity will tackle this problem head-on, studying the mineralogical composition of the surface to discover what mysterious past this planet is hiding.

What is Mars's climate like?

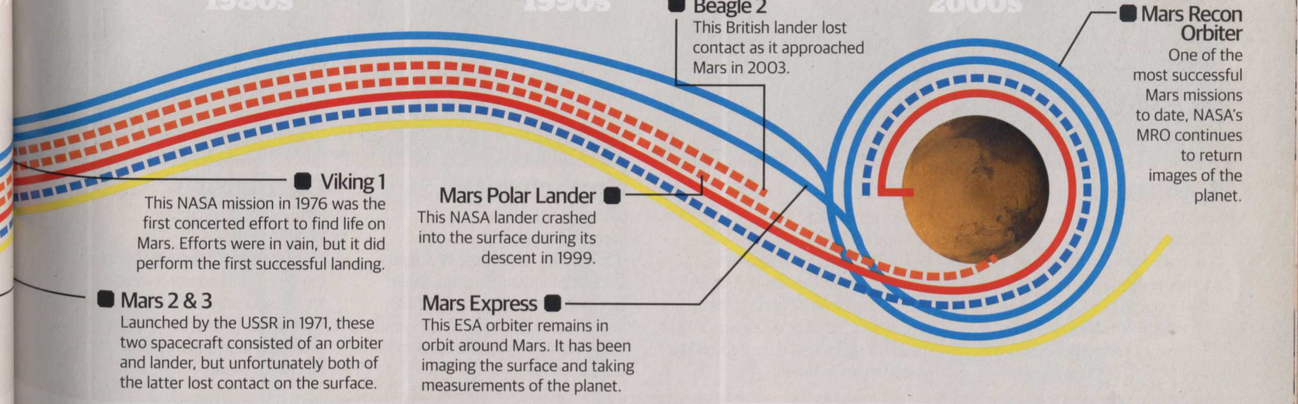
It is thought that in the past Mars may have been warmer and therefore had a thicker and wetter atmosphere compared to the thin, cold atmosphere it has now. The determination of whether water exists underground or once gouged the surface is imperative as life as we know it cannot exist without water. By measuring elements such as carbon, Curiosity will look for abrupt changes in the abundance of certain elements that could be associated to life forms.

Does Mars have a volatile history?

It is generally accepted that Mars is a much different world to what it was a few hundred million years ago, but what caused this change is still unknown. Of great interest to Curiosity will be Mount Sharp, in the Gale Crater. This mountain could have layers of sedimentary deposits of Martian history, similar to the layers of deposits we see on Earth. By studying various rocks and soils on Mars, Curiosity will be able to understand some of the geological processes that sculpted Mars.

Could we launch a human mission to Mars?

The Sky Crane is the only current landing method that can land 1,000kg (2,200lb) on the surface of another world, a necessity for a manned mission. By demonstrating that the Sky Crane works, Curiosity will pave the way for human explorers to use the same design to land on Mars. In addition, Curiosity will also study the levels of radiation to unearth any potential hazards that might face future explorers.


1980s
1990s
2000s
Beagle 2
This British lander lost contact as it approached Mars in 2003.
Mars Recon Orbiter
One of the most successful Mars missions to date, NASA's MRO continues to return images of the planet.
Viking 1
This NASA mission in 1976 was the first concerted effort to find life on Mars. Efforts were in vain, but it did perform the first successful landing.
Mars Polar Lander
This NASA lander crashed into the surface during its descent in 1999.
Mars 2 & 3
Launched by the USSR in 1971, these two spacecraft consisted of an orbiter and lander, but unfortunately both of the latter lost contact on the surface.
Mars Express
This ESA orbiter remains in orbit around Mars. It has been imaging the surface and taking measurements of the planet.

This mosaic of Curiosity, with Mount Sharp in the background, was put together using 55 images taken by the Mars Hand Lens Imager (MAHLI)

Curiosity: the first 12 months

In August 2012, the most ambitious robotic vehicle ever devised landed on Mars on a mission to probe the Red Planet for signs of past and present habitability. We spoke to the team's deputy project scientist one year after about Curiosity's accomplishments at that point, and what they hoped it would be doing in the years that followed **Written by Jonathan O'Callaghan**

On 6 August 2012 the world watched in awe as a rover the size of a car descended to the surface of Mars under a rocket-powered contraption and touched down. Almost a decade in the making, the Mars Science Laboratory (MSL), better known as the Curiosity rover, has been a massive success story for NASA. Never before has such a large and complicated vehicle landed on another world.

In just 12 months after Curiosity went operational it made some tentative steps towards achieving its numerous goals, which include assessing Mars for signs of past and present habitability. NASA was careful to only take baby steps in its first 12 months, but in the following year Curiosity was pushed to the limits as it explored its surroundings and headed towards its ultimate goal, Mount Sharp (a mountain also known as Aeolis Mons), which rises 5.5 kilometres (3.4 miles) above the floor of Gale Crater and has layers of sediments that may hold clues about the Red Planet's history.

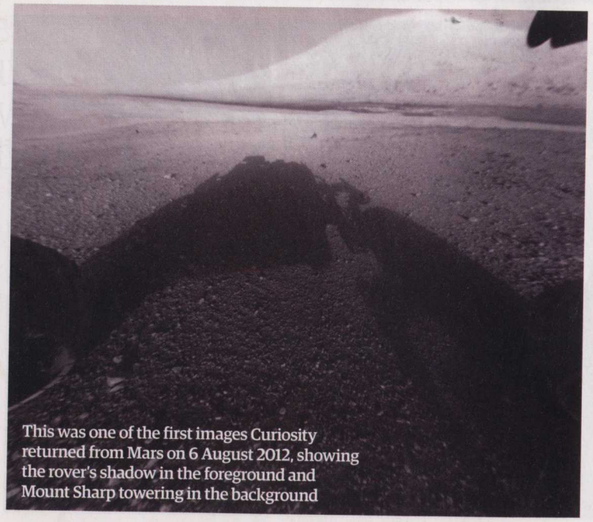
"When you land you have this incredible burst of adrenaline," Dr Joy Crisp, the deputy project scientist for the MSL mission, told **All About Space**. "But a lot of this first year involved [testing] of more and more [of our] capabilities. We needed to test things out on Mars before we went crazy, but now we are a lot more confident in the rover."

That's not to belittle any of the accomplishments of Curiosity however. After only a few tentative steps, the rover found evidence of a watery past on Mars and returned stunning high-resolution images from the surface.

The first piece of evidence of Mars's wet past that was discovered by Curiosity came from "conglomerate rock with rounded pebbles in it," Dr Crisp explained. "When we looked at those pebbles and saw how rounded they were, that led the science team to be able to figure out how deep the water had to have been and how fast it was flowing. They were able to determine that those rocks were deposited from a stream."

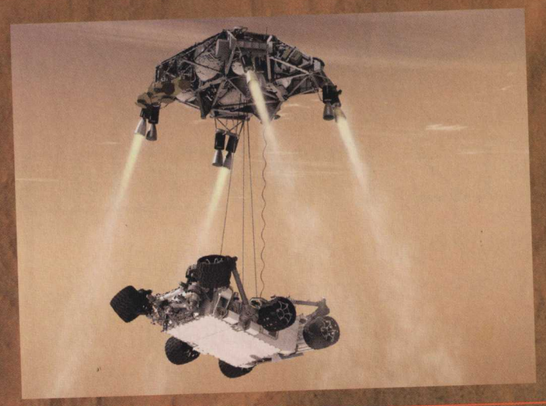
With groundbreaking discoveries like this already being made, we expect great things from Curiosity in its future as the team became more confident in its abilities.

In the year after the rover landed, the MSL team at NASA's Jet Propulsion Laboratory in California made great strides in their operations to make sure they get the most out of the mission. "We try to come up with better ways to do operations, so we've had to make changes along the way to make the whole operations



This was one of the first images Curiosity returned from Mars on 6 August 2012, showing the rover's shadow in the foreground and Mount Sharp towering in the background

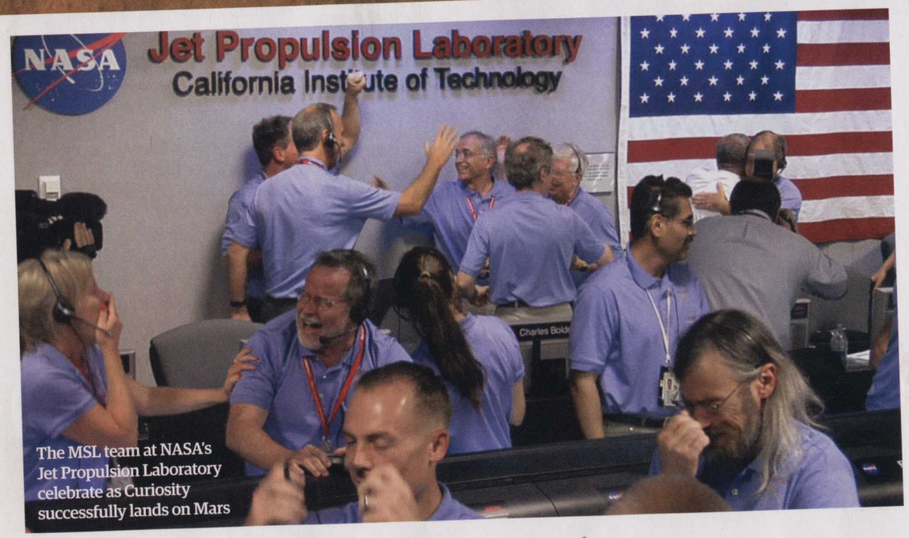
A year on Mars



6 August 2012
Bradbury landing site
Using the revolutionary Sky Crane mechanism, Curiosity successfully lands on Mars 2.4km (1.5mi) from the centre of its wide target area.

19 August 2012
First laser shot
During its first two weeks Curiosity tests several of its instruments, including the firing of its ChemCam laser for the first time on 19 August 2012 on a rock called Coronation (or N165).

29 August 2012
Driving begins
Curiosity begins its first drive on 29 August to an area called Glenelg about 400m (1,300ft) east of its landing site.



The MSL team at NASA's Jet Propulsion Laboratory celebrate as Curiosity successfully lands on Mars

timeline go faster," said Dr Crisp. "We started out working on Mars time [one Martian day is 37 minutes longer than an Earth day], taking about 16 or 17 hours preparing the rover's commands for the next day, and we've gotten that down to 11 hours now, so we can work more normal hours."

Considering the complexity of the mission, it's remarkable that things went so smoothly in the first 12 months, barring one mishap. "It's performed very well," agreed Dr Crisp, "but we did have one hiccup where one side of the computer had an issue, so we had to switch to the other side, but overall everything has been functioning okay. It's a very, very complicated beast and it takes a lot of effort [for] everybody to understand that complexity and be able to plan what the rover should do each day."

19 September 2012
First contact
Curiosity uses the Mars Hand Lens Imager (MAHLI) and Alpha Particle X-Ray Spectrometer (APXS) to touch and study a rock, named Jake Matijevic, for the first time.

27 September 2012
Streambed found
Images of what appears to be an ancient streambed on Mars are returned by Curiosity. NASA confirms the findings several months later.

7 October 2012
First scoop
Curiosity collects its first scoop of Martian soil at a location known as Rocknest to be analysed by the SAM (Sample Analysis at Mars) and CheMin (Chemistry and Mineralogy) instruments.

8 February 2013
First hole drilled
Curiosity uses its drill at the end of its robotic arm for the first time on a patch of flat rock called John Klein, making a hole 2cm (0.8in) deep.

3 December 2012
Water discovered
Evidence of water molecules on Mars, in addition to sulphur and chlorine, is discovered by Curiosity as it performs its first extensive soil analysis.

To Mount Sharp

4 April 2013
Curiosity goes quiet
From 4 April to 1 May Curiosity operates autonomously on the Martian surface due to Mars being on the opposite side of the Sun from Earth, making communications difficult.

5 June 2013
Journey to Mount Sharp
NASA announces that Curiosity is getting ready to begin its year-long trip from Glenelg to the base of Mount Sharp, a journey of over 8km (5mi).

"We needed to test things out on Mars before we went crazy, but now we're a lot more confident in the rover"

Dr Joy Crisp, MSL's deputy project scientist

As mentioned earlier, the primary objective of Curiosity's mission is to ascend Mount Sharp and study the mountain's various sedimentary layers. However, as Curiosity's projected landing site was within an area 19 kilometres by 7 kilometres (12 miles by 4 miles), NASA was unsure where exactly the rover would land. Ultimately it touched down just a few kilometres from the centre of this area, near a region of particular interest known as Glenelg. So, rather than rushing straight to Mount Sharp, NASA made the decision to explore the flat plain of Gale Crater first, and then take another look at Glenelg on its way back, if possible.

"Looking at where we landed from the orbiter images we realised it would make sense to first go over to Glenelg and check out these different rocks that we could see before heading over to Mount Sharp," explained Dr Crisp. But while the lifetime of the rover was set at a lowest estimate of two years, "if it's anything like Spirit and Opportunity this rover may last much longer than two Earth years," which gives Curiosity plenty of time to study Mount Sharp. In fact, NASA extended the operational lifetime of the mission indefinitely, giving the MSL team funding to continue driving the rover until it stops working, which could be several decades from now.

Aside from observing pebbles in an ancient streambed, indicative of a wet past on Mars, Curiosity also tested out its other instruments to ensure they were working normally ahead of some planned hardcore science for the rover. "We're looking for past environments that could have been suitable for life," explained Dr Crisp, "and liquid water is key for life as we know it. So getting over to Yellowknife Bay [a Martian outcrop in the Glenelg area] and drilling into sedimentary rock and discovering abundant clay mineral, which has a lot of bound water in it that can only form in the presence of liquid water, was a major find."

Not all of Curiosity's instruments had returned data with such a high level of interest at that point, though, but of most importance to Dr Crisp was ensuring that "the instruments were working well." One

EMAIL HOLETOANOTHERUNIVERSE404

NWEDAY APRIL 15TH

- PACE WEBINAR 12
- EMAIL NOAA - REORDER
  - EARTH.MD SUNOMI
  - VIIRS USE CASE =
    FUNDING JUSTIFICATIO
  - INVENTORY JPL/NOAA
    BUILDS
- AM RIVERFLOW PM=SAME
  → BAYBRIDGE
  ALINE → LONGBEACH

MONDAY APRIL

RIVERFLOW: ALINE TO AZUSA 9:15 AM
HIGHLAND PARK / SPRINGDALE
FLOW: FLOOD / NORMAL
HEAVY CAR TRAFFIC
HERITAGE / CHINATOWN
- AWAY FROM HILLS

- MIA - STEPPIN' UP → BEC
  - CHILDISH GAMBINO?
  - MATT DAMON?
- BIT BUCKET: FOOTER!
- TOGEAR BEC

Curiosity in numbers

The facts and figures about NASA's flagship Mars rover

899 kilograms
Mass of the Curiosity rover

$2.5 billion
Total cost of the Mars Science Laboratory mission

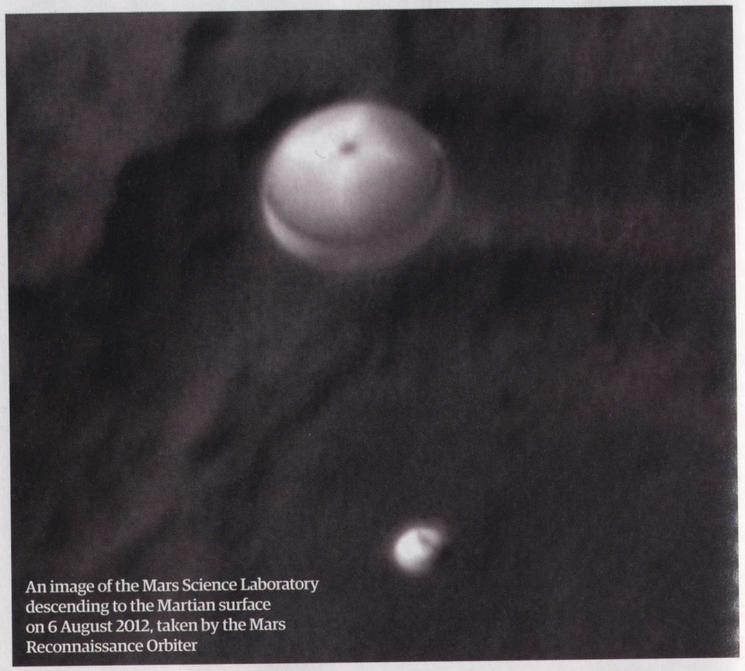
14 minutes
Time it takes to send a command to Curiosity

55 years
Upper estimate of Curiosity's possible operating lifetime

10
Number of scientific instruments on board Curiosity

5 *Curiosity is about 5 times larger than its predecessors Spirit and Opportunity*

668 *Number of Martian days (sols), or 687 Earth days, the primary mission lasted*



An image of the Mars Science Laboratory descending to the Martian surface on 6 August 2012, taken by the Mars Reconnaissance Orbiter

Five key instruments on Curiosity

ChemCam
The Chemistry and Camera complex (ChemCam) uses a small laser to vaporise rocks or soil up to 7m (23ft) away and analyses the emitted spectrum of light to determine the target's characteristics.

SAM
The Sample Analysis at Mars instrument suite studies samples scooped up by Curiosity. The entire suite accounts for more than half of Curiosity's science payload.

APXS
The Alpha Particle X-Ray Spectrometer (APXS) is used to measure the abundance of particular chemical elements in rocks and soil.

Mastcam
The main camera on Curiosity is the Mast Camera, or Mastcam for short. It has two camera systems mounted on a mast extending up from the rover itself to take high-resolution images and video.

MAHLI
The Mars Hand Lens Imager at the end of Curiosity's arm can study objects of interest up close. This is also where the drill is located to bore holes into the Martian surface.

of the most important instruments on the Curiosity rover is SAM (Sample Analysis at Mars), a suite of instruments comprising over half of the rover's scientific payload that can scoop up soil samples and analyse them in an on-board laboratory. "We sent the SAM instrument to look for organic compounds," said Dr Crisp, "but we knew it was going to be like looking for a needle in a haystack. It's not easy to find organic compounds preserved in ancient rocks even on Earth, so we didn't really expect to hit it on the first try." SAM, however, was expected to be one of Curiosity's most valuable assets when it comes to studying the sedimentary deposits on Mount Sharp.

With the first year behind them, the MSL team were eager to really get the wheels rolling and make use of Curiosity as best they could. According to Dr Crisp, in the next 12 months "we will be driving a lot further than we've done so far, heading towards Mount Sharp, so we don't know what exactly we'll encounter or what we'll see from our cameras on the surface. We can see from orbit that we might want to stop a handful of times on our way to Mount Sharp but we don't want to get bogged down unless there's something really amazing that we discover on the way. So [in the next 12 months] we'll be doing a lot of driving, and if you've seen the pictures of Mount Sharp with the layering it looks really fascinating. So I think that will be a magnetic pole for our team to psychologically want to keep going, because as we drive the detail of what we can see in those hills is going to get more and more interesting," she added.

While Curiosity's predecessors Spirit and Opportunity (neither of which are currently operational) have travelled tens of kilometres on the surface, never before has a rover attempted to scale a mountain on Mars in the way Curiosity did. But, as Dr Crisp explained, the team believes the rover will have no problems making its way to a higher altitude. "The wind should not be a problem," she said, "and it'll be interesting for the meteorological instrument to measure that. The steepness we believe will also be okay, based on studying the 3D models we have from our orbiter data. When we actually get there and see the terrain up close our 3D models will improve and we may have to adjust our routes based on that newer data as well as finding out how much the rover slips on different kinds of rock."

So, with the most exciting part of Curiosity's mission yet to happen, Dr Crisp highlighted a "combination of new things" that would be of most interest to both scientists and the public alike in the coming year. "I'm hoping that we're going to see some new rock types and new landforms that tell us about other things that went on in the past on Mars," she said. And with the public clamouring for more astounding science and incredible imagery from Curiosity, the rover's mission could only get better and better as the team becomes more confident in their operation of one of the greatest and most ambitious space exploration missions of all time.

The goals

Has Curiosity acomplished what it set out to do?

Did it demonstrate the ability to land a large rover on Mars?
Yes. The car-sized Curiosity rover successfully landed in Gale Crater by the foot of Mount Sharp.

Did it reach Mount Sharp?
Yes. On 11 September 2014 the rover arrived at the foot of the mountain. It then proceeded to travel up and collect rock samples.

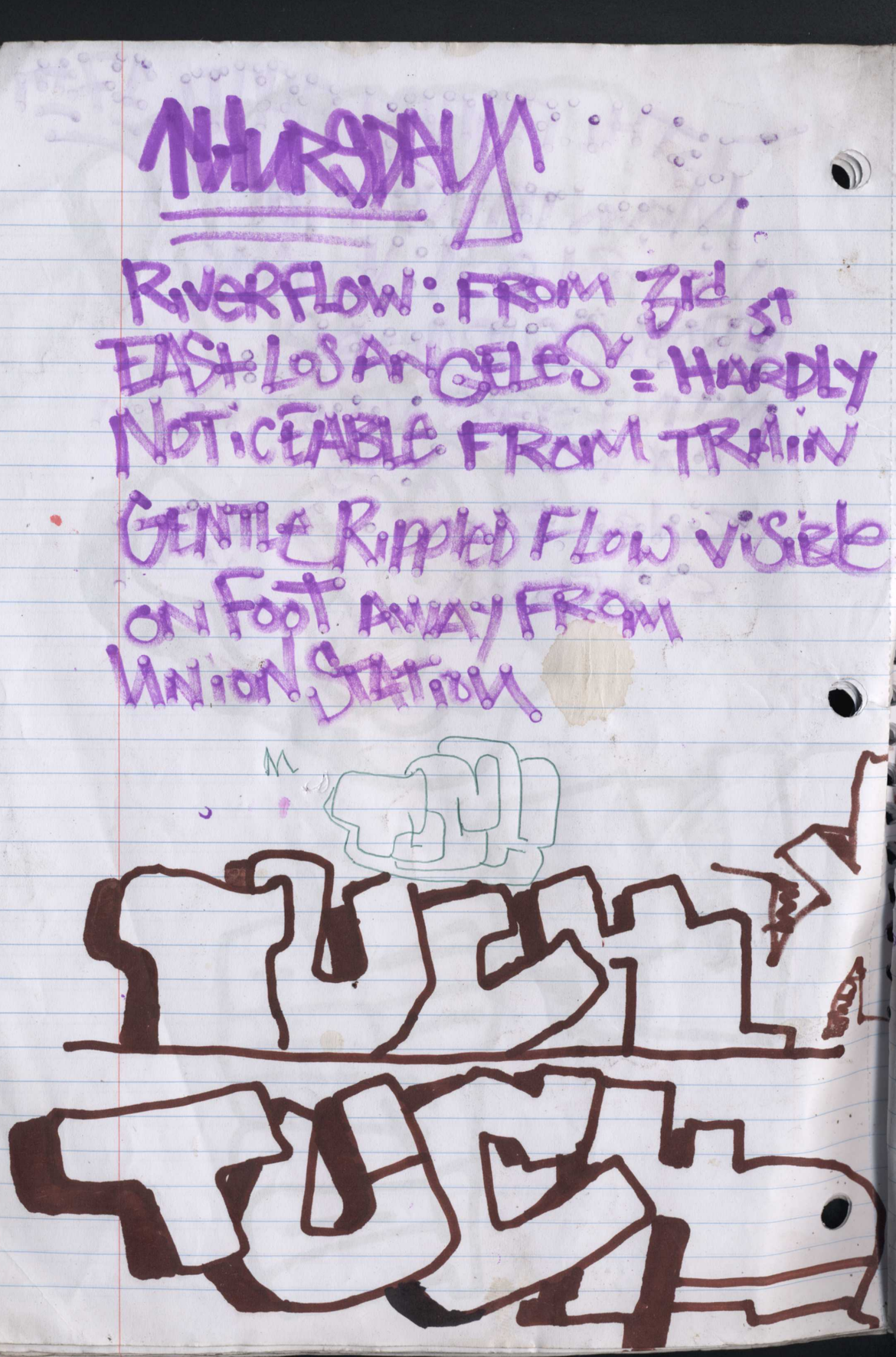
Did it discover new rock types on Mars?
Yes. After drilling into sedimentary rock and analysing the samples, the rover discovered tridymite, a silica mineral often occuring in volcanic rocks, which wasn't thought to be present on Mars.

Did they determine the climate and geology of its landing area? Did it confirm ancient lakes?
Yes. Over six years the rover, using its Sample Analysis at Mars (SAM), found that Mars has seasonal variations in its levels of methane, higher in warmer weather and seeing a drop in colder periods. It also found evidence in Gale Crater to suggest that billions of years ago Mars was home to lakes.

Did it determine the habitability of the planet?
Yes. Curiosity discovered that Mars' radiation levels were much higher than previously thought, beyond NASA's limit for astronauts. For humans to live on the planet, scientists would need to design habitats to accomodate the high radiation levels.

THURSDAY

RIVERFLOW: FROM 3rd ST
EAST LOS ANGELES = HARDLY
NOTICEABLE FROM TRAIN
GENTLE RIPPLED FLOW VISIBLE
ON FOOT AWAY FROM
UNION STATION



APRIL 6th

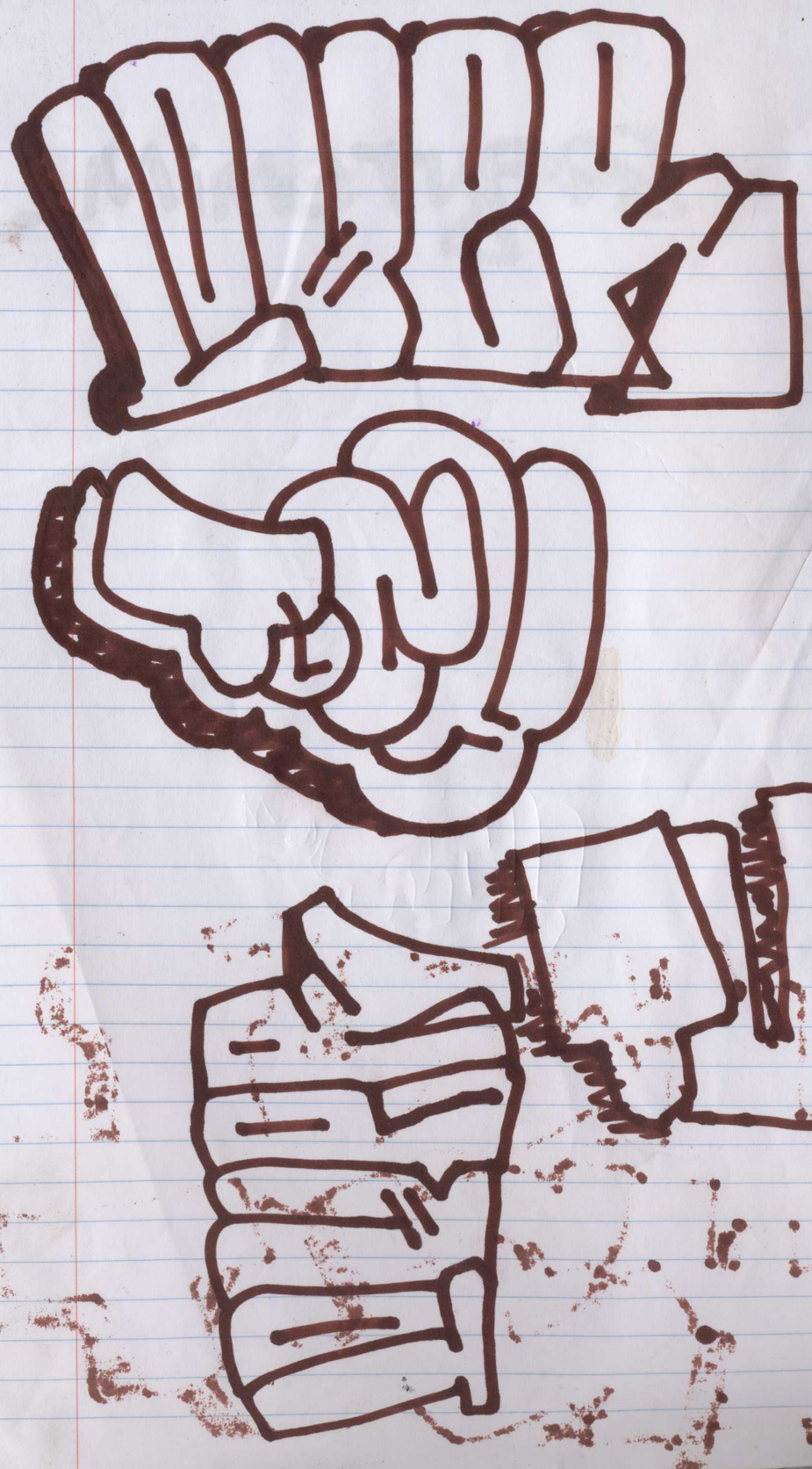
7:09AM

WEDNESDAY!!!

RIVERFLOW
FROM METRO TOWARD UNION STA.

- TRACE RIVER ON MAP
- VIIRS/MODIS/AQUA
- NEARSPACE NETWORK
- CSS FIRST WORD [redacted]EBullet
- ELECTRIC INFRASTRUCTURE SOCAL
- SPERIDIAN TECHNOLOGY
- LAND MANAGMENT SYSTEM
LONG BEACH
- COUNCIL WOMAN 8TH DISTRICT
-25-55033
LONG BEACH COMPANY AGENDA!
- HAKIM CHAMBERS
ALEJANDRA RAMIREZ

DEPT. WATER POWER



THURSDAY APRIL 17TH

MOUNTAINS NOT VISIBLE 9:15 AM FROM CLOUD COVER.

MTN PEAKS VISIBLE FROM COMPTON 9:23

RIVER FLOW → BAY 9:35 AM

SATURDAY

- Container SWATCH
- FLEX ITEMSIZING
- EASTER ON ADAMS
- Reshard MRO → ARCHIVE → M
- MOON.md ON MRO - RANGER9

SUNDAY

- ACTBME + LA 311 → EMAIL POINTY.

- NOAA Articles

20 min Background cleanup

MARS INVENTORY

orbit:
- MRO: MARS RECONNAISSANCE ORBITER
- MARS Odyssey
- VIKING
- MAVEN
- ESA EXOMARS
- TGO: TRACE GAS ORBITER
- ISRO: MARS ORBITER MISSION
- MOM: MARS ORBITER
- MARS EXPRESS
- MARS GLOBAL SURVEYOR
- MARINER

ROVERS
- OPPORTUNITY
- SPIRIT
- CURIOSITY
- PERSEVERANCE
- OPTIMIST
- SOJOURNER - ED. DESTINY DEPRECATED?

SPACE X + VIRGIN ORBIT:
REFERENCE [PDS, ATLAS]
LANDERS: INSIGHT
VIKING
SKY CRANE

M3M
Myles MEDA
MARTIAN GOTHIC
THE martian 2015

ARCHITECTURE
MARS RELAY
NETWORK

MONDAY!

- SCAN
- FAMILY.MD [POSTBUNDLES, INCLUDE BUNDLES]
- TABLE INVENTORY.MD
- MARS V3

RIVERFLOW A.M. = OCEAN

- MOUNTAIN PEAKS VISIBLE REST OBSCURED BY LOW CLOUD

-DENIAL OF SERVICE?

ERIKA JOHNSON ROLE AS PRIMARY QUEEN WAS WELL CONNECTED DIGITALLY, NOT MANY INTERRUPTIONS SHE IS A LIGHT SKIN BLACK GIRL OF MOORISH PACIFIC DESCENT, THUS WAS AN ITEM IN THE POOP BROWN BLACKASS SOUTH. THE NORMANI THAT WAS KASH DOLL IT MEGAN THEE STALLION IS DARK BROWN. WHEN SHE BECAME PRIMARY MY DIGITAL LIFE COLLAPSED. ERIKA IS NOT AS STABLE BUT TIMES CHANGED and our WEB is OPEN DISTRIBUTED SERVICES for COMMON WEB USERS. #KASH DOLL has CHANGED MY VIEW OF DATA. SHE IS A VICTIM OF HUMAN TRAFFICKING

_/_INCLUDES/MRO(("JUNO"))

TITLE
ORGANIZATION
CAT FILE
MS DEVICE + CAP
FLEXBOX RESULTS

PRESS

EYES.NASA.GOV

DEVICES AND SCREEN NAME CHANGES CONSTANTLY IN COMPARISON. PRIMARY FOR HER IS BEING HER ROADIE, SO IF I LOOSE A DEVICE KEEPING HEALTHY ONLINE HAD A DIFFERENT APPROACH. KEEP LOGINS HEALTHY, DELETE VIDEO DAILY

RECOVERED
BROTHER
HARD
MISS SOM MARS PETS
MOON LOVER 404